Department of Materials Science and Engineering
Pohang University of Science and Technology

AMSE502 Phase Transformations

due Date: Oct. 21, 2014 Prof. Byeong-Joo Lee

Problem Set #2 calphad@postech.ac.kr
Room 1- 311

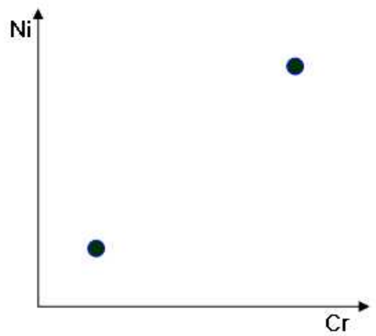
1. To harden fully a sheet of low-alloy steel during a quench (to 0°C) from an initial temperature, T_o, the sheet must be cooled at 200 K s^{-1} in the vicinity of 925 °C.

   a) Write the power series solution to this problem. Let h be the thickness of the sheet and α the thermal diffusivity.
   b) Sketch the temperature at the sheet's center as a function of time, as estimated by the first term approximation of T(x,t). Under what conditions is the approximation valid to within 5%.
   c) Develop an expression for the cooling rate at the center of the steel sheet and determine when a one-term approximation is valid to within 5%.
   d) Calculate the cooling rate at the sheet's center when its temperature is 600 °C.
   e) Estimate the maximum sheet thickness that can be hardened fully in this quenching medium. α = 0.15 cm^2s^{-1}. Comment on how your result depends upon the steel's initial temperature. Do not conclude that there is no dependence simply because T_o does not appear in your final expression. The latter was derived on the basis of simplifying assumptions made earlier. Examine these assumptions in order to explain the relationship between cooling rate and T_o.

2. Consider injection of an alloying element B in a metallic matrix A. The initial composition of B in A is 0.01. Injection is carried out by maintaining the surface composition of B to be 0.05. The diffusion coefficient of B in A is 4.529×10^{-7} exp[-147723(J)/RT] (m^2/s). The injection temperature is between 1173K and 1473K. Injection distance is defined to be the distance from the surface of a point where the composition of B is half of the target value (0.03). Using the diffusion simulation code (FDM.for), perform the followings:

   (a) How does the injection distance depend on injection time?
   (b) How does the injection distance depend on temperature?
   (c) How can you determine the activation energy for the reaction, and what is it?

3. Draw a diffusion path qualitatively for a reaction between a high Cr-Ni Fe-based alloy layer and a low Cr-Ni Fe-based alloy layer. Consider the given mobility data in Fe.



data) $M_{Cr}\, RT$ = 3.5E-4 exp(-286000/RT)
$M_{Ni}\, RT$ = 3.5E-5 exp(-286000/RT)

※ Don't try to make any quantitative calculation. Qualitative but scientific explanation is important.

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4. For an n-component substitutional solid solution phase, based on an assumption of equal partial molar volume of all substitutional elements and within a volume fixed frame of reference, the interdiffusional flux of species *k* can be expressed as follows:

$$J_k = -\sum_{j=1}^{n-1} D_{kj}^n \nabla C_j$$

(a) Derive the following mathematical formalism for the multicomponent diffusion coefficient

$$D_{kj}^n = \sum_{i \in S} (\delta_{ik} - x_k)\ x_i \Omega_i \left(\frac{\partial \mu_i}{\partial x_j} - \frac{\partial \mu_i}{\partial x_n} \right)$$

(b) Using the equation in (a), show that the interdiffusion coefficient in an A-B binary substitutional solid solution can be expressed as follows :

$$\tilde{D} = [x_A \Omega_B RT + x_B \Omega_A RT] \left(1 + \frac{d \ln \gamma_B}{d \ln x_B} \right)$$

(c) By applying the formalism in (a) to an A-B-B* ternary system, show that the $\Omega_B RT$ is the tracer diffusion coefficient of element B, D_B^*.